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Nitrate, Nitrite and Ammonia Contamination in Ground Water: A Case Study from Gümüþhacýköy Plain, Turkey

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Abstract: Ground and surface water quality can be affected by three different forms of pollution, which are chemical, biological and physical pollution. These polluting factors can influence natural environment and human health. Nitrates in soil and ground water generally moves relatively slow and there is approximately 20 years lag time between the detection of the pollutant and the pollution activity in ground water. For that reason, it is assumed that nitrate concentration can continue to affect current polluting activities for several decades. In this study, groundwater pollution originated from agricultural activities were investigated in Gümüþhacýköy urban area. The concentrations of nitrate (NO_3^-) in groundwater of Gümüþhacýköy Plain range from 0-15.61 mg/l, nitrite (NO_2^-) 0-0.007 mg/l and ammonium (NH_4^+) 0-0.5 mg/l. However other chemical parameters such as pH, EC, TH, Ca^{+2}, Mg^{+2}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{-2} and F^- were measured.

Key words: Ammonia, contamination, ground water, Gümüþhacýköy Plain, nitrate, nitrite.

Introduction

Ground water is the only source for drinking water and domestic use in many parts of the world. Groundwater pollution, originated from human activities and urbanization reduces the supply of potable and safe drinking water and threat public health. There is NO_3^--N in ground water naturally, but it can be harmful to the environment and human health at high concentrations (Harrison, 1992). Unlike water from wells of public systems in urban areas, private residential wells are not systematically observed and analysed for pollution. Septic tank and wastewater pond uses, atmospheric deposition, disposal of wastes, industrial wastewater discharges and especially animal farming and agricultural fertilizer applications are the main sources of ground and surface water contamination (Aelion and Conte, 2004). Nitrate from such sources can be infiltrated into surface and groundwater systems via runoff and infiltration (Limbrick, 2003).

The most common contaminant in ground water is dissolved nitrogen in the form of nitrate (NO_3^-), owing to its high water solubility. This contaminant becomes increasingly widespread due to agricultural activities and disposal of sewage on the land surface. Although NO_3^- is the major form in which nitrogen occurs in ground water, there is also dissolved nitrogen in the form of ammonium (NH_4^+), ammonia (NH_3), nitrite (NO_2^-), nitrogen (N_2) and organic nitrogen (Freze and Cherry, 1979). A decrease in the redox potential of the ground water can, in some situations, contribute denitrification, a process in which NO_3^- is reduced to N_2O or N_2. There are these reaction products in the ground water as dissolved species. From a groundwater-quality viewpoint, denitrification is a desirable process. Raised concentrations of dissolved N_2 and N_2O are not detrimental to drinking water. In contrast, NO_3^- at concentrations above 45 mg/l renders water unfit for consumption by human infants (Freze and Cherry, 1979).

Nitrate in ground water generally originates from nitrate sources on the land surface, in the soil zone, or in shallow subsoil zones where nitrogen-rich wastes are buried. In some situations, NO_3^- that enters the groundwater system originates as NO_3^- in wastes or fertilizers applied to the land surface. In other cases, NO_3^- originates by conversion of organic nitrogen or NH_4^-, which occur naturally or are introduced to the soil zone by human activities. The process of conversion of organic nitrogen to NH_4^- is known as ammonification. Through the process of nitrification, NH_4^+ is converted to NO_3^- by oxidation (Freze and Cherry, 1979).

In ground water and surface water, the nitrate is normally at low level, but it can reach high concentration as a result of lechate originated from human or animal wastes and agricultural runoff (World Health Organization, 1998). Groundwater pollution by nitrates is a worldwide problem mainly associated with the excessive use of fertilizers in intensive agriculture (World Health Organization, 1985; U.S.EPA, 1993). Previous studies showed that rural land uses, especially agricultural applications, can lead nitrate to ground water. Non-agricultural sources of nitrogen, such as septic systems, waste water ponds and leaking municipal sewers, are generally less important regionally but may affect ground water locally (Hudak, 1999; Fetter, 1999).

Groundwater pollution can result in poor drinking water quality, loss of water supply, high clean-up costs, high costs for alternative water supplies, and or potential health problems (Nas and Berktay, 2006).

The dominant nitrogen species in ground water is nitrate (NO_3^-), then to a lesser extent ammonium ion (NH_4^+). Agricultural applications containing the use of fertilizers consisting of nitrogen, cattle feeding operations and the cultivation of the soils are significant sources of pollution. The main health effects associated with pollution by nitrogen compounds are methemoglobinemia, a type of blood disorder in which oxygen transport in young babies or unborn foetuses is impaired or the possibility of forming cancer-causing compounds after drinking polluted water (Domenico and Schwartz, 1990).

Ground water serves as a significant source of fresh water all over the world, supplying water for domestic, industrial and agricultural use. Ground water is preferable owing to its lower cost and higher quality where surface water use is diminishing because of contamination by industrial plants and its restricted use in drought periods (Sakiyan and Yazýcýgil, 2004).

Because the concept of safe yield ignores the discharge from the aquifer by evapotranspiration or into streams, groundwater management policies based upon it ended up with some unintended consequences, such as drying up of streams and springs with loss of ecosystems, contamination of groundwater by polluted streams and when withdrawals exceeded the recharge on a continual basis, eventual depletion of the aquifers (Sophocleous, 1997, 2000 and Bredehoeft, 1997).

There have been reports of groundwater contamination in many aquifers throughout the world and a very wide range of pollutants have been recognized, including N species, heavy metals, phenols, pesticides, major inorganic species and bacteria. Nitrate (NO_3^-) is the main form of N which occurs in groundwater and is becoming increasingly widespread because of agricultural activities. This has happened in several places in the world, including Turkey (Sakiyan and Yazýcýgil, 2004).

Although the history of geological and hydrogeologic investigations in the Gümüþhacýköy Plain dates back to 1893, the first detailed report named "Hydrogeologic Report of the Artesian Wells in the Merzifon-Gümüþhacýköy Plain" was prepared by Dr. Recep Egemen in 1955. The critics of the former wells, evaluation of drilled wells, geologic and hydrogeologic properties of the aquifer were elaborated in this report. The groundwater reservoir was calculated as 124×10^6 m^3/year. Moreover, the study suggests the drilling of new wells and taking the control of artesian wells (DSI, 1973).

According to the study named "Brief Information about the Merzifon-Gümüþhacýköy Groundwater" carried out by Tufan Subaþý in 1967, discharge of the artesian wells was calculated as 5.2×10^6 m^3/year and detailed hydrogeologic studies were suggested.

The report named "Irrigation from groundwater of the Merzifon-Gümüþhacýköy Plain" was prepared by the State Hydraulic Works in 1973 (Altuð and Ertuðrul, 1973). According to this report groundwater reservoir was calculated as 25×10^6 m^3/year and the report indicates that 4600 hectares could be irrigated with 15 l/sec - 160 wells (DSI, 1973).

On a large part of the Gümüþhacýköy Plain (AMASYA) irrigated agriculture is carried out and fertilizers are applied. The ground water is extracted by wells drilled in the alluvium of the Gümüþhacýköy Plain to meet municipal, industrial and other water requirements. The ground water of the plain has been polluted by agricultural activities, irrigation channels and domestic waste water. Groundwater pollution in the alluvium aquifer of Gümüþhacýköy was investigated during a one-year study from July 2003 to August 2004. The aim of the study was to evaluate the characteristics of the groundwater chemistry and pollution of the aquifer of the Gümüþhacýköy Plain. Detailed analysis on the hydrogeology and hydrogeochemistry of the investigation area was produced within the framework of the study. In this paper, the characteristics, distribution and variation of the NO_3^-, NO_2^- and NH_4^+ pollution are presented based on 2003 and 2004 data using Geographic Information System (GIS) technology.

GIS Approah

Geographical Information Systems (GIS) are information systems gathering, storage and analysis of spatial data as a whole (Yomralýoðlu, 2002) and GIS is a powerful tool with great promise for use in environmental problem solving. Most environmental problems have an obvious spatial dimension and spatially distributed models can interact with GIS (Goodchild et al., 1993). For that reason, GIS plays a very important role in data management applications. Because there are a lot of data in planning and operation stage in many management programmes, GIS applications are very significant in water management.

A simple GIS-linked model for groundwater nitrate transport in the GIS environment was developed by Lassere et al. (1999).

Lee et al. (2003) developed statistical models for groundwater quality using GIS. The NO_3^--N concentrations were higher in shallow wells (less than 40 m) than in deep wells (deeper than 40 m) in both dry and rainy seasons.

Babiker et al. (2004) focused that groundwater pollution by nitrate is closely related to one specific land use class, the “vegetable fields”. The nitrate concentration in ground water under vegetable fields was significantly higher than that under urban land or paddy fields.

General Properties of Study Area

Gümüþhacýköy Plain is located in the western part of the Amasya city and northern part of Turkey. The plain is about 65 km far from city of Amasya. The plain covers an area of about 126 km^2, and recharge area of the Gümüþhacýköy Plain is 1050 km^2. Figure 1 shows the location of the study area. The plain is a generally flat area with low rolling hills in the eastern part of Gümüþhacýköy. However, the plain is morphologically mountainous in the southern and northern parts of Gümüþhacýköy. Ground water is supplied to wells and springs by two principal aquifers. The tuff, tuffite, agglomerate and volcanic lava differ from sand, clay and gravel in topographical shape. The neogene field was eroded by the river and flood waters and as a result it turned out to have a wavy structure. The volcanic field has a more flat shape with respect to Neogene.

The drainage system in the plain is affected by the tectonically structure. It is observed that Gümüþsuyu River, Köseler River, Paþa River and Müþrüf River follow fault lines.

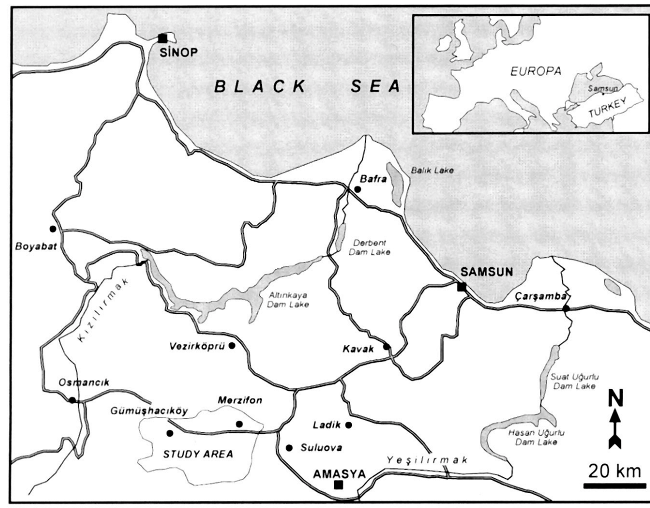

Figure 1: Location map of the study area

The unit containing ground water is made up of Quaternary alluvium and Pliocene clay, sand and gravel. The recharge in the area takes place through the rain and the infiltration of surface flow while the discharge takes place through wells and springs. Dry climate conditions are dominant in the plain. Based on the data of the Merzifon Meteorological Station for the period of 1965-2000, the average annual precipitation is 409 mm, while the average temperature is 11.25°C and average evaporation is 751.75 mm (DSI, 1973).

During the last 20 years, industry and agricultural activities have been developing at an accelerated rate in Gümüþhacýköy Town. The main industries in the region are sugar-beet processing, sunflower processing, textile and wood products. Agricultural activities in the town are quite intensive. The crops grown in the plain are grains, sugar-beet, sunflower, onion, potato, poppy, maize, vegetables and fruits.

Geologic Setting

In the area studied, the Paleozoic metamorphic suit is the oldest formation. This unit consists of clayey schist, chlorite schist, and green schist, marble and recrystallized limestone. The jurassic limestone, with fossils which are generally compact and overlie uncomfortably metamorphic suit in the plain are situated in the area. Cretaceous limestone, pinky coloured, very hard, recrystalized and very fissured, overlies Jurassic limestone. Cretaceous limestone outcrops on the high altitudes in the plain. The flysich series with mixed volcanic material composed of conglomerate, green and black sandstone, shale, marl, limestone, andesite, tuff and tuffite are deposited in the Upper Cretaceous. Senozoic started with the Eocene flysich in the study area. Flysich consists of sandstone, shale, sandy limestone, marl, locally conglomerate, tuff and agglomerate. Catchment area was filled with continental material of 1000-1500 m thickness affected by east-west elongated faults in the Neogene. These thick series consist of Miocene blue clay and marl on the lower part; Pliocene sand, clay, gravel and a mixture of these on the upper part. The layer thickness ranges from 10 to 50 cm in these series. The silty and clayey layers are light brown and yellowish; gravely and sandy layers are greyish in colour. The layers, very loose, are not continuous and change its lithology in short distances. This unit gradually gets harder as one goes deeper and it turns out to be conglomerate. Of the gravels about 5-10 cm in diameters there are some blocks which are 50 cm. 95% of these gravels and blocks are generally rounded and are composed of volcanic material. The quaternary is characterized by the alluvium and the alluvium cone consisting of detrical material that comes from north and south with the flood waters. Alluvium cone, of 10-60 m thickness and take form gravel, sand, clay and mixture of these, form along the Gümüþsuyu River, Köseler River, Çorak River and Salhan River. A simplified geological map of the study area is shown in Figure 2 (DSÝ, 1973).

Hydrogeology

The most important geological units for groundwater transport in Gümüþhacýköy Plain are Quaternary alluvium and Pliocene clay, sand, gravel and mixture of these. It is seen that the distinguishing of Pliocene series and Quaternary alluvium is very challenging when the drilling cores in the plain are observed, as these two units have same lithologic features. The plio-quaternary aquifer is unconfined at high altitudes in the north and west, but confined at low altitudes. The other rocks underlying the alluvium do not bear significant amounts of ground water.

Because the area between the northeast of the plain and the Merzifon Cone is composed of clay and marl layers, there is no ground water. The alluvium cone composed of coarse grained and dry rivers coming from the north and gathered by the river in front of the fault line is very important in terms of the groundwater transport. The thickness of plio-quaternary loose material ranges from 20 to 150 m in this area. The aquifer around Gümüþhacýköy consists of gravel of great size, clay and clayey gravel and its thickness ranges from 50 to 350 m.

The wells used to supply water for various purposes (municipal, industrial and irrigation) have been drilled in the alluvium aquifer. During the first phase of the study, in July 2003, 16 wells were identified and hydrogeological data were collected. 32 wells were studied in August 2004 in the second phase. The depth of the wells range between 50 m (minimum) and 290 m (maximum), discharge rates between 5 and 60 l/sec. Presently, new wells are still being drilled and operated by the State Hydraulic Works Samsun City, as the water requirements of the city constantly increase. Moreover, private owners around the city also operate a number of groundwater wells. Groundwater levels have been measured in April and October from 1976 till today. The levels change between 0 and 56.11 m below the ground surface. Average water level fluctuations were about 2-3 m between dry and wet seasons. The general directions of the groundwater flow are from northwest to southeast.

Groundwater recharge in the Gümüþhacýköy Plain is through the infiltration of precipitation and influent surface water (Gümüþ River and Köseler River) and irrigation channels. Domestic wastewaters of the town infiltrate into the aquifer and contaminate the ground water.

Methodology

In the study, groundwater samples were collected from the wells in Gümüþhacýköy Plain and in-situ measurements and laboratory analyses were carried out on the samples. Water samples were gathered from the wells in polyethylene bottles, and filtered through ash-free filter paper and split into two parts. This part was acidified with 5% nitric acid for analysis. pH and electric conductivity (EC) were measured in the laboratory, and temperature of the waters were measured in-situ using portable instruments.

Major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}), anions (HCO_3^-, Cl^-, SO_4^{-2}), NH_4^+, NO_2^- and NO_3^- analyses of the groundwater samples were determined by titration in State Hydraulic Works Quality Control Laboratory.

A vector-based GIS software package ArcGIS 8.3 was used to map query and analyze the data in this study. The well locations were obtained for 49 wells spreading all over the region by using Garmin hand held Global Positioning System (GPS) receiver. GPS technology proved very useful to increase the spatial accuracy of the various data integrated in the GIS. In addition, attribute information of the layers was also input in the data digital map using ArcGIS 8.3 software.

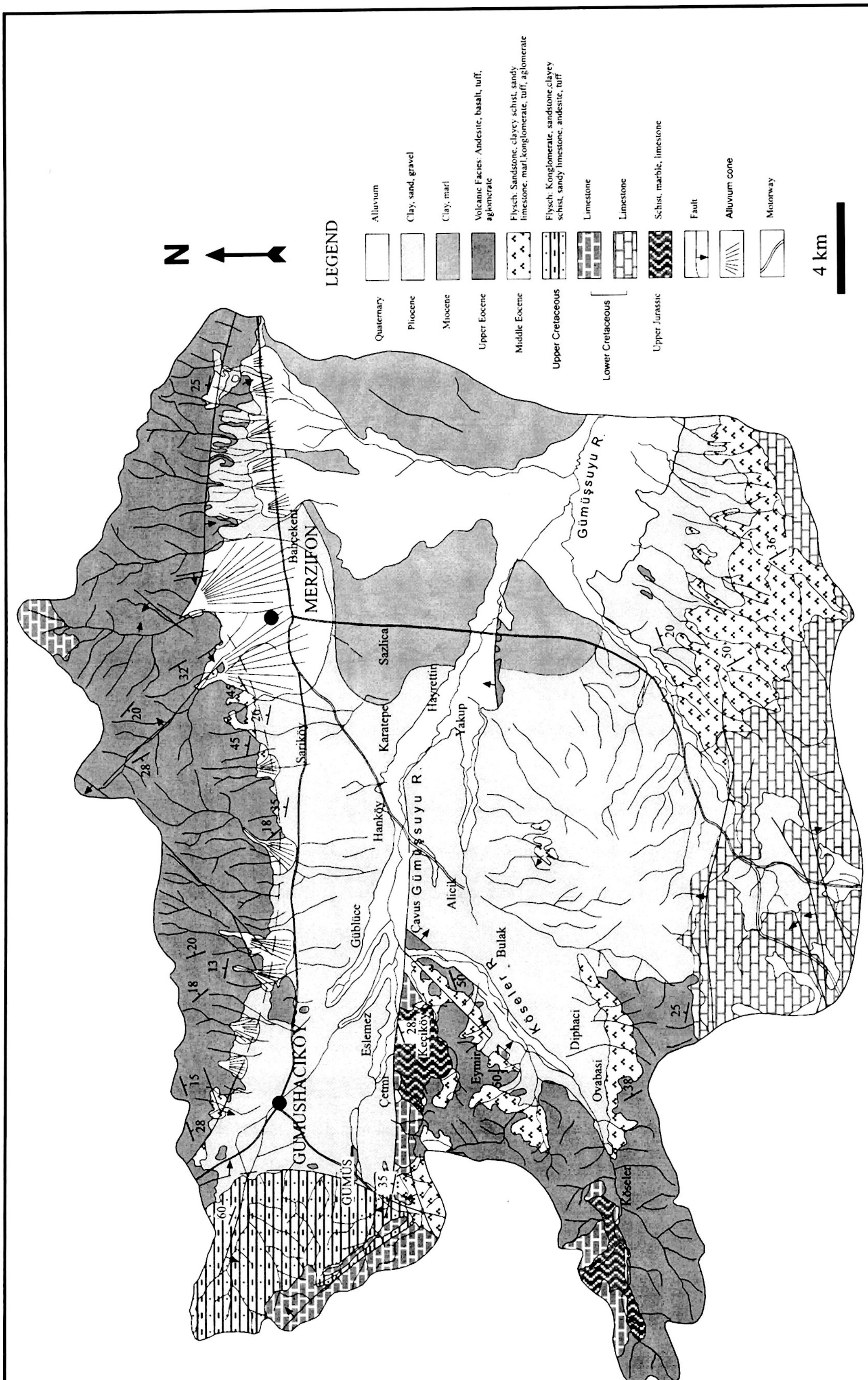

Figure 2: Geological map of the Gümüþhacýköy Plain.

Hydrogeochemistry

The well waters of the Gümüþhacýköy Plain have been used for municipal, industrial and irrigation purposes. Totally 49 well water samples are studied in the plain. 35 water samples are used for irrigation and industrial while 14 water samples are used for drinking purposes.

The pH values of all samples range between 6.8 and 9.9. pH value of the Keçiköy drinking water (well number 14) is 6.9 and this value is below the standards of Turkish Drinking Waters. pH values of the other drinking water samples are situated between the standard values. EC values change between 439 and 1276 µS/cm. Total hardness values of the samples range between 2.5 and 57.75 according to the French Hardness and change between “very soft” and “very hard” water types. pH, EC and TH values are shown in Table 1 and chemical analyses results are shown in Table 2. Between 22,013

Table 1: pH, EC and Total Hardness value of the samples

Well number	**22013**	**17156**	**53060**	**52990**	**53055**	**20099**	**22191**	**23**	**53806**	**20175**	**4**	**14581**	**14583**
pH	6.9	8	7.9	8	7.3	7.2	6.9	7.4	7.2	7.6	7.4	7.4	7
EC × 10^6 (25 ^{0}C)	724	729	601	546	596	617	979	723	659	509	638	587	1276
TH	36.75	23.25	26.5	22	28.75	29.5	47.25	31.25	28.5	22.5	30.75	28	57.75
Well number	**14584**	**2**	**19308**	**28798**	**30714**	**52424**	**52425**	**22160**	**22163**	**20852**	**20850**	**53030**	**32**
pH	7.1	6.8	6.9	7	9.9	8.7	7.9	8.2	8.2	8	8.2	7.7	7.4
EC × 10^6 (25 ^{0}C)	915	646	745	646	551	653	1224	950	755	560	540	640	918
TH	38.75	30.75	35.5	31.5	2.5	20.9	35.55	32.75	29.15	21.9	19.35	25.4	41.2
Well number	**33995**	**66**	**18743**	**50362**	**53054**	**52989**	**45472**	**57919**	**7216**	**47**	**25**	**39**	**100**
pH	7.4	7.3	7.2	6.9	7	6.9	7.2	7	7.3	8.2	8.1	7.4	7.3
EC × 10^6 (25 ^{0}C)	632	704	796	755	612	827	551	816	571	1122	714	694	643
TH	32.9	35.2	37.15	41.4	33.85	42.7	29.15	41.95	27.65	35.05	27.45	34.95	32.4
Well number	**101**	**102**	**103**	**27**	**64**	**28**	**14**	**16**	**5**	**17**			
pH	7.2	7.4	7.1	7.4	7.5	7.1	6.9	7.3	7.1	7.3			
EC × 10^6 (25 ^{0}C)	665	620	714	598	612	673	476	683	479	–			
TH	34.95	32.45	38.95	37.45	32.4	33.9	36.65	24.9	37.15	25.1			

Table 2: Chemical analyses results of the water samples

Well number	**22013**	**17156**	**53060**	**52990**	**53055**	**20099**	**22191**	**23**	**53806**	**20175**	**4**	**14581**	**14583**
Ca^{+2}	91.2	58.1	69.1	58.1	77.2	82.2	133.3	79.2	73.1	63.1	83.2	84.2	147.3
Mg^{+2}	34	21.3	22.5	18.2	23.1	21.9	34	28	24.9	16.4	24.3	17	51.1
Na^{+}	29.9	69.9	29.9	26.91	16.1	17.04	28.98	34.96	28.98	23	11.96	14.03	42.09
K^{+}	1.95	2.34	1.56	1.56	0.78	1.56	3.12	1.56	1.17	1.17	1.56	1.17	5.07
HCO_3^{-}	373	247.5	225	320	245	245	385	270	275	220	282.5	220	445
Cl^{-}	11.4	19.9	21.3	15.6	19.9	12.8	44	9.9	18.5	11.4	9.94	9.9	60.4
SO_4^{-2}	109.4	107.5	73.9	39.4	48.5	68.2	88.8	102.2	46.6	38.9	37.4	74.9	139.7
NH_4^{+}	0	0	0	0	0	0	0.05	0.1	0.15	0.15	0.05	0.4	0.05
NO_2^{-}	0	0	0	0	0	0	0	0	0	0	0	0	0
NO_3^{-}	4.63	3.03	5.36	2.93	5.07	4.96	1.313	5.54	3.23	5.17	2.62	5.88	15.61
Well number	**14584**	**2**	**19308**	**28798**	**30714**	**52424**	**52425**	**22160**	**22163**	**20852**	**20850**	**53030**	**32**
Ca^{+2}	89.2	92.8	104.2	88.2	4	36	57	50	75	54	47	55	100
Mg^{+2}	40.1	19.5	23.1	23.1	3.6	28.6	51.1	48.6	24.9	20.1	18.2	28	38.9
Na^{+}	42.09	13.11	19.09	11.04	106.3	59.11	126.04	69.92	41.86	29.9	37.3	31.05	49.91
K^{+}	3.12	6.24	2.34	6.63	0.78	1.95	3.51	1.17	1.95	1.56	3.51	1.95	1.56
HCO_3^{-}	320	275	297.5	307.5	21.5	275	340	352.5	257.5	245	250	227.5	337.5
Cl^{-}	32.7	12.8	21.3	11.4	18.5	14.2	35.5	48.3	15.6	18.5	14.2	11.4	14.2
SO_4^{-2}	112.3	49	69.2	23	14.9	41.8	231.4	55.7	99.8	13	7.2	75.8	156.5
NH_4^{+}	0	0	0	0	0.3	0.1	0.1	0.1	0.05	0.05	0.05	0.2	0.05
NO_2^{-}	0	0	0	0	0	0.001	0.001	0.004	0.004	0	0	0	0

(contd.)

Table 2 (contd.)

NO_3^-	10.69	4.05	7.74	3.85	0	0.1	7.3	6.75	3.35	3.05	3.35	3.4	4.55
Well number	**33995**	**66**	**18743**	**50362**	**53054**	**52989**	**45472**	**57919**	**7216**	**47**	**25**	**39**	**100**
Ca^{+2}	86	78	97	112	104	110	84	89	73	55	48	81	77
Mg^{+2}	27.4	37.7	31	32.2	18.8	36.5	19.5	41.3	22.5	51.1	37.1	35.3	31.6
Na^+	17.94	23.92	41.86	23	13.11	39.1	13.11	22.08	17.94	101.89	49.91	23.92	28.98
K^+	1.56	1.95	1.95	1.17	0.78	1.17	1.17	1.95	1.17	1.95	1.95	2.73	5.46
HCO_3^-	307.5	345	302.5	377.5	257.5	310	232.5	325	235	385	250	320	375
Cl^-	11.4	9.9	14.2	7.1	18.5	17	24.1	15.6	25.6	53.3	21.3	9.9	9.9
SO_4^{-2}	43.2	43.7	135.4	73.4	80.2	170.4	51.4	116.2	42.7	107	99.4	66.2	3.4
NH_4^+	0	0	0	0.05	0	0	0	0.05	0.05	0.5	0.05	0.2	0
NO_2^-	0	0	0.03	0.001	0.002	0	0	0	0.002	0	0.002	0	0
NO_3^-	2.7	4.75	6.7	4.95	9.3	6.25	9	8	7.35	6.35	4.65	1.8	1.05
Well number	**101**	**102**	**103**	**27**	**64**	**28**	**14**	**16**	**5**	**17**			
Ca^{+2}	71	62	93	88	80	90	101	64	92	73			
Mg^{+2}	41.3	40.7	37.7	37.1	29.8	27.4	27.4	21.3	34	16.4			
Na^+	14.95	13.1	19.09	11.96	13.11	14.03	23	14.03	16.1	13.11			
K^+	5.07	5.46	3.12	0.78	1.17	1.56	0.78	0.78	1.17	0.78			
HCO_3^-	372.5	340	400	372.5	337.5	310	307.5	195	320	225			
Cl^-	7.1	8.5	8.5	7.1	8.5	21.3	11.4	8.5	8.5	11.4			
SO_4^{-2}	3.8	5.8	20.2	16.3	2.9	28.8	88.8	69.1	71.5	37			
NH_4^+	0	0	0	0	0.1	0	0.1	0.05	0	0			
NO_2^-	0	0	0	0	0	0.004	0.001	0.001	0	0.001			
NO_3^-	0.95	3.25	0.05	2.3	0.65	2.3	5.9	4	5.5	5.1			

and 7216 numbered wells are used for irrigation purposes while between 47 and 17 numbered wells are used for drinking purposes in the plain.

Drinking and irrigating water samples are of the Ca-HCO_3 water type according to the Piper Diagram (Figures and 4). All drinking waters have the same properties; carbonate hardness bigger than 50%, alkalis and the weak acids dominate the groundwater (Figure 3). Well waters used for irrigating purposes have the carbonate hardness bigger than 50% except the 30,714 numbered well water samples. On this water sample, carbonate alkali is bigger than 50% (Figure 4).

Nitrogen species and phosphate are the major components of the municipal wastewater and some industrial facilities. Ammonia, ammonium salts, nitrate and orthophosphates originate from agricultural and residential cultivated lands as fertilizers. Nitrate is the main form of the nitrogen in groundwater. Nitrite is generally found in low quantities in waters, is unstable in the presence of oxygen, and occurs as an intermediate form between ammonia and nitrate or nitrite and nitrogen gas (McNeely et al., 1979).

The most serious pollution that has occurred in the ground water at the Gümüþhacýköy Plain as a consequence of human activities is from nitrogen compounds (NH_4^+, NO_2^-, NO_3^-). The concentrations of NH_4^+, NO_2^- and NO_3^- in the alluvial groundwater were in the ranges 0 to 0.5, 0 to 0.007 and 0 to 15.61 mg/l respectively. There are 14 well water samples analyzed as drinking water from the 49 samples in the ground water of the Gümüþhacýköy Plain. Nitrate (NO_3^-) values of the drinking waters did not exceed the limit of 45 mg/l (TSE, 1986 drinking water standard). Most of the samples high in nitrite (NO_2^-) and ammonium (NH_4^+) concentrations and exceeding the limit of 0 mg/l (TSE, 1986 drinking water standard) were taken from drinking water wells in the plain. Nitrite and ammonium values are higher than the 0 mg/l in Hayrettin, Karatepe, Bulak, Ovabaþý, Keçiköy, Çavuþ, Eymir and Eslemez villages drinking waters. These wells should not be used for drinking purposes.

Chemical analyses were done in 2003 and repeated in 2004. According to first analyses results the minimum nitrate concentration is 2.62 mg/l. The maximum concentration, 15.61 mg/l, was measured for 14,583 numbered well. Average value of the nitrate concentration data of 2003 is 6.12 mg/l in 16 wells. The minimum and maximum nitrate concentrations are observed to be 0 and 9.3 mg/l with the average value of 4.21 mg/l in 32 wells according to the 2004 year analyse results.

For the samples taken from wells in 2003 and 2004, a statistical evaluation of nitrate concentrations can be seen

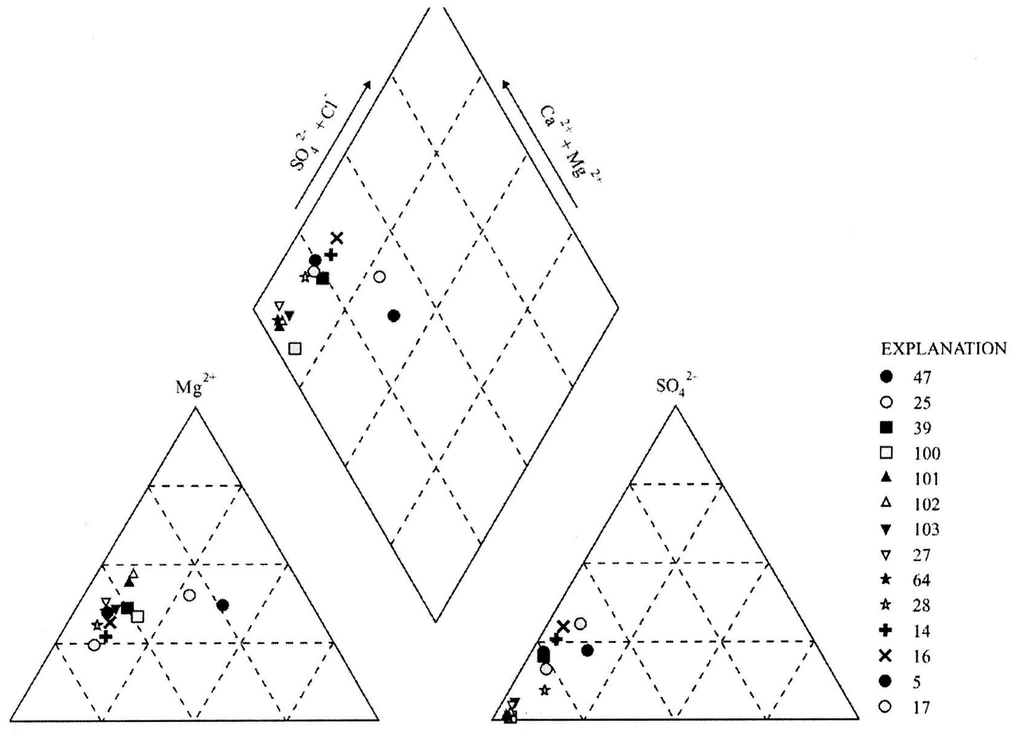

Figure 3: Piper Diagram of the drinking waters in the Gümüþhacýköy Plain.

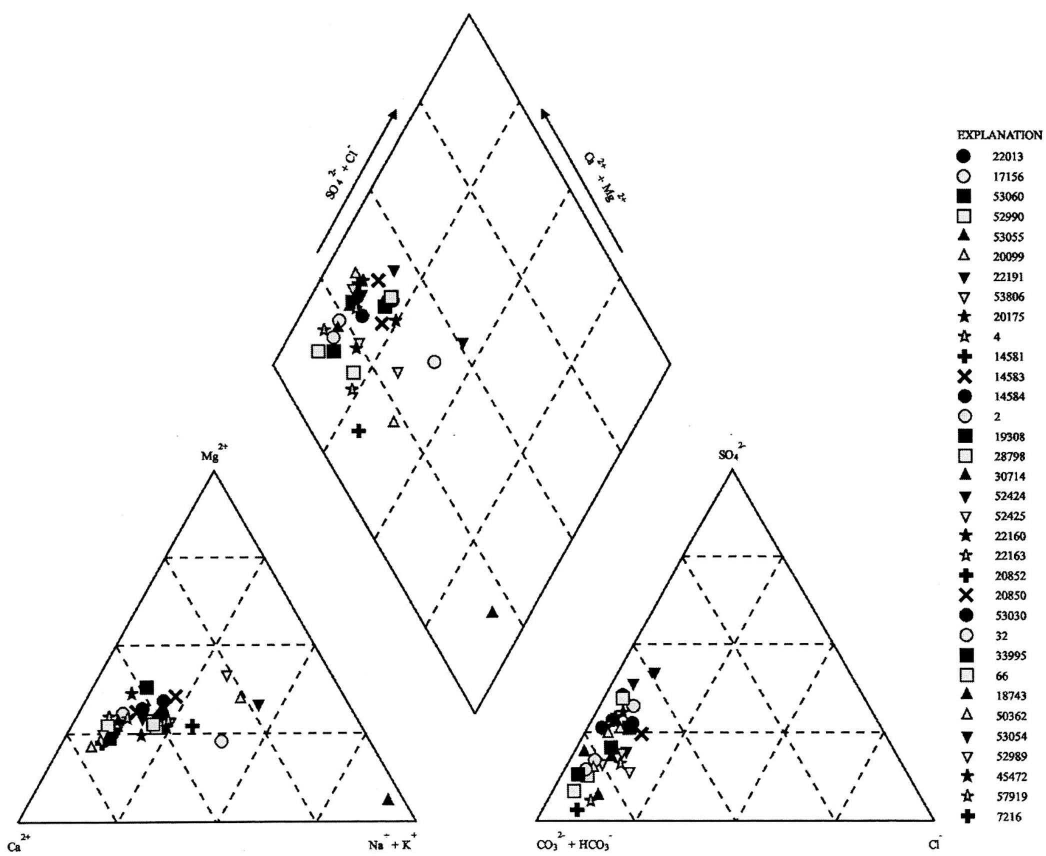

Figure 4: Piper Diagram of the irrigating waters of the plain.

in Table 3. It can be seen that in Table 1 none of the 16 wells had a nitrate concentration below 2.5 mg/l by the year 2003. From 2.5 mg/l to 5 mg/l nitrate concentration was measured for eight wells out of 16 wells in 2003. In addition, between 2.5 and 5 mg/l was observed in the data from 11 wells in 2004. From 5 to 10 mg/l nitrate concentrations were obtained from five wells out of 16 wells in 2003; 12 wells out of 34 wells in 2004. From 10-50 mg/l nitrate concentrations were obtained from three wells out of 16 wells in 2003 and none of the 34 wells had a nitrate 10-50 mg/l (Figure 5).

A linear regression analysis on NO_3^- concentration was applied to determine if well depth (m) and NO_3^- (mg/l) concentrations are important. Tables 4 and 5 show the results of the linear regression analysis for the distribution of NO_3^- concentration. According to the results, regression sum of squares is 5.994, residual sum of squares is 338.901, coefficient of determination, R-squared is 0.017. Equation of the relation between well depth and NO_3^- concentration is $Y = - 0.0106259X + 6.83697$. A negative correlation could be expected but correlation coefficient has very low value. Linear regression analysis revealed that, but non important, negative relation between nitrate contents and well depth (Figures 6 and 7). Figure 6 shows the relationship between NO_3^- concentration and well depth. According to this curve there is negative correlation but not significant.

To determine if well depth (m) and NH_4^+ (mg/l) concentrations are significant, a linear regression analysis was applied on NH_4^+ concentration. According to the analysis coefficient of determination, R-squared is 0.0034. Equation of the relation between well depth and NH_4^+ concentration is $Y = 0.000132431X + 0.0427337$. A positive correlation could be expected but correlation coefficient has very low value. Linear regression analysis revealed that, but non significant, positive relation between NH_4^+contents and well depth could be considered (Figure 7).

Table 3: Statistical evolution of nitrate concentrations in 2003 and 2004

Nitrate concentrations (mg/l)	*2003*		*2004*	
	Number	*%*	*Number*	*%*
Less than 1	-	0	4	12.5
From 1-2.5	-	0	5	15.62
From 2.5-5	8	50	11	34.38
From 5-10	5	31.25	12	37.5
From 10-50	3	18.75	-	-
Total number of wells	16	100	32	100
Minimum	2.62		0	
Maximum	15.61		9.3	
Median	5.015		4.85	
Average	6.12		5.04	
Standard deviation	3.818		2.74	

Table 4: Linear regression analyses results of the NO_3^- concentration

	Sum of Squares	*df*	*Mean of Square*	*F*	*Sig.*
Regression	5.994	1	5.994	0.513	0.48
Residual	338.901	29	11.686		
Total	344.896	30			

Table 5: Equation of the relations between well depth and NO_3^- concentration

	Unstandardized coefficients		*Standardized Coefficients*	*t*	*Sig.*
	B	*St.Error*	*Beta*		
Constant	6.837	2.012		3.398	0.002
Var.	-0.01062	0.015	-0.132	-0.716	0.48

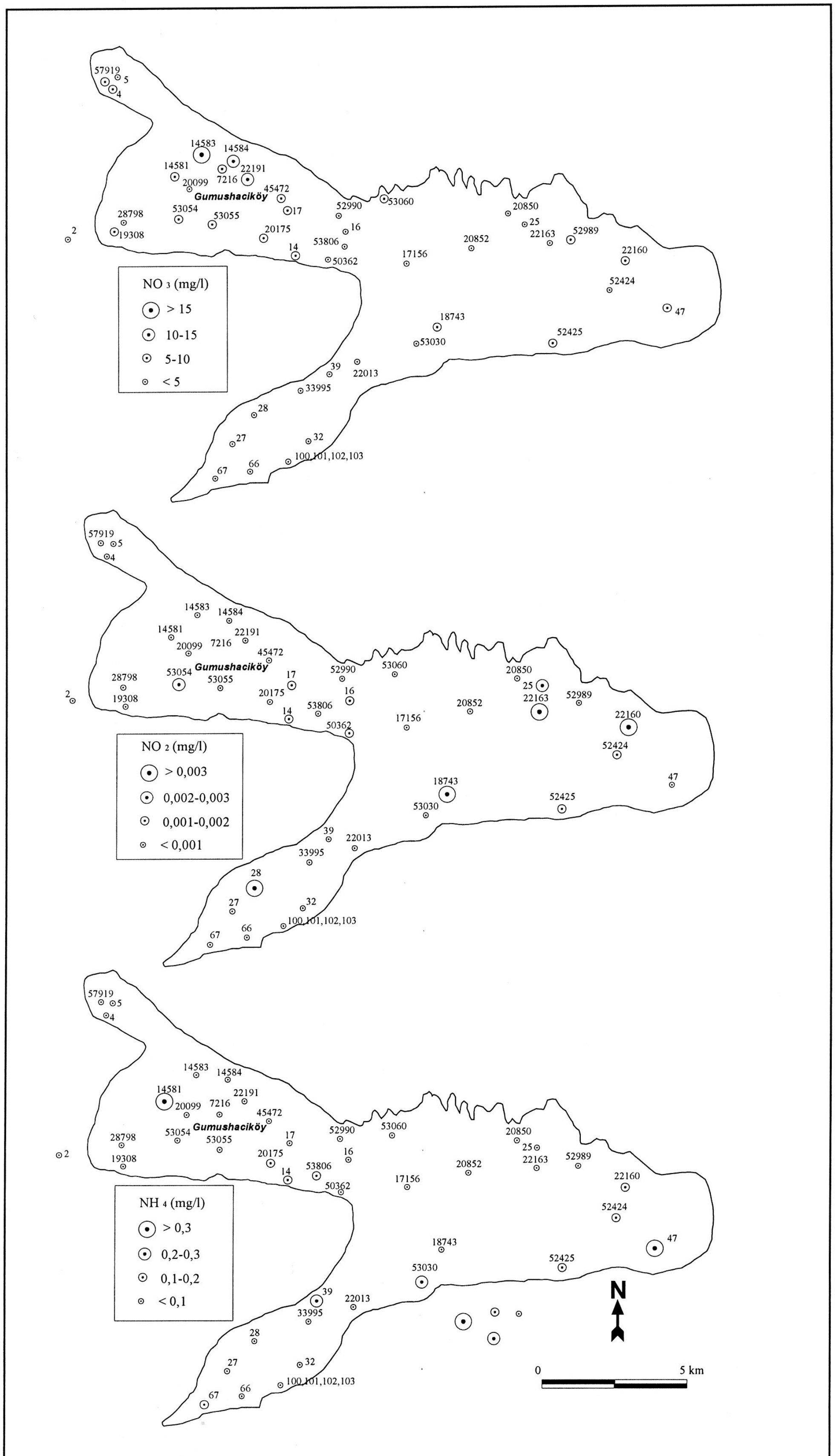

Figure 5: Spatial distribution of NO_3^-, NO_2^- and NH_4^+ concentrations.

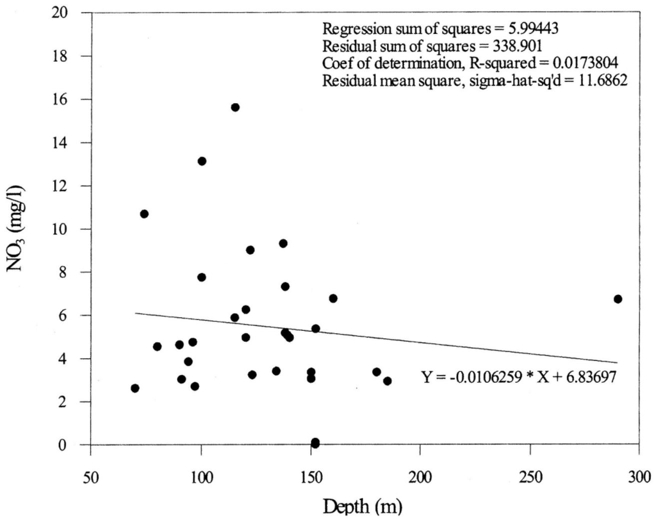

Figure 6: NO_3^- concentration versus well depth.

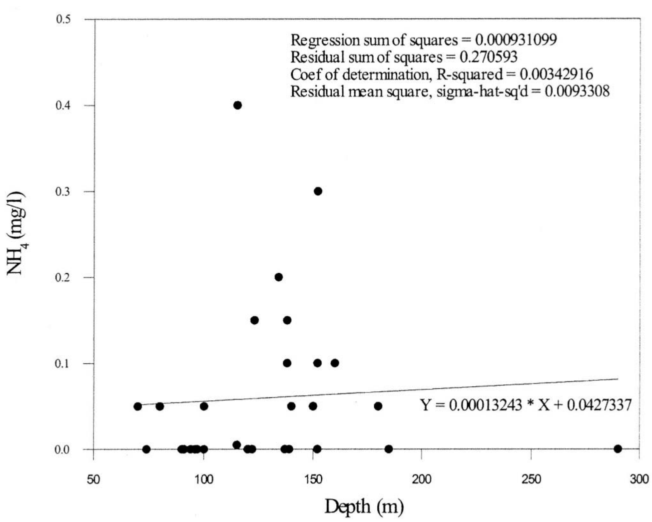

Figure 7: NH_4^+ concentration and well depth relation.

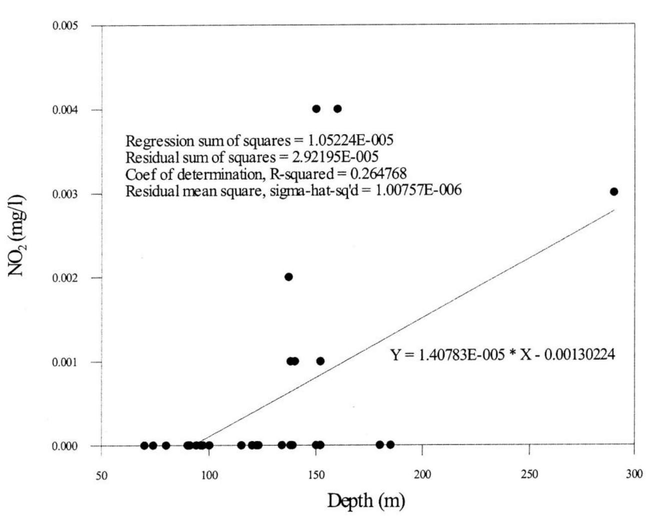

Figure 8: Relation between NO_2^- concentration and well depth.

To determine if well depth (m) and NO_2^- (mg/l) concentrations are significant, a linear regression analysis on NO_2^- concentration was performed. According to the results, coefficient of determination, R-squared is 0.2647. Equation of the relation between well depth and NO_2^- concentration is $Y = 1.40783E - 005X + -0.00130224$. A positive correlation could be considered but correlation coefficient has very low value. Linear regression analysis revealed that, but non significant, there is positive association between NO_2^- contents and well depth (Figure 8).

Conclusions and Results

The ground water in the alluvium aquifer of the Gümüþhacýköy Plain has been polluted via agricultural activities and municipal wastewaters. The water analyses from 49 wells in the plain, taken over a 2-year period, were used to determine the NO_3^-, NH_4^+ and NO_2^- contamination in the ground water.

Spatial distributions of nitrate concentrations were evaluated using GIS for the groundwater wells in the Gümüþhacýköy Plain. There was a negative correlation, but non significant, between nitrate and well depth (R-squared = 0.017). Linear regression analysis between NH_4^+ and well depth were done and R-squared obtained as 0.0034. Positive correlation could be considered between them. According to linear regression analysis results between NO_2^- concentration and well depth, positive relation is expected but non significant.

Water quality analyses were done in 2003 and 2004. pH value of the Keçiköy drinking water is 6.9 and this value is below the standards of Turkish Drinking Waters. EC values change between 439 and 1276 µS/cm. Total hardness values of the samples range between 2.5 and 57.75 according to the French Hardness and change between "very soft" and "very hard" water types. Drinking and irrigating water samples are of the Ca-HCO_3 water type according to the Piper Diagram. Well waters using for irrigating purposes have the carbonate hardness bigger than 50% except the 30,714 numbered well water sample. On this water sample, carbonate alkali is bigger than 50%.

There were 14 well water samples analyzed as drinking water from the 49 samples in the ground water of the Gümüþhacýköy Plain. Nitrate (NO_3^-) values of the drinking waters did not exceed the limit of 45 mg/l (TSE, 1986 Drinking Water Standard). Most of the samples high in nitrite (NO_2^-) and ammonium (NH_4^+) concentrations and exceeding the limit of 0 mg/l (TSE, 1986 Drinking Water Standard) were taken from drinking water wells in the plain. There are eight villages where the value of nitrite and ammonium has exceeded the Turkish standard in the plain.

Drinking water quality measurements have to be made more frequently, at six months intervals for instance. It is essential to monitor the water quality and to take precautionary steps if necessary.

Since there are so many possibilities, it is often difficult to pinpoint sources of nitrate. From the results of this study, it is believed that increase in nitrate concentration come from a variety of factors. These factors include the location of the wells within the plain, intensive agricultural activities in the villages of the Gümüþhacýköy Plain, growing industrial activity in the city centre.

The present state of the quality of the Gümüþhacýköy ground water necessitates taking some technical measures in order to preserve and improve water quality. The measures should include: construction of a sewer system extending throughout the Gümüþhacýköy urban area to collect municipal wastewaters, treatment of collected municipal wastewaters, irrigation channels and septic tanks, collection and treatment of industrial wastewaters.

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